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# Status and progress of the National Ignition Facility as ICF and HED user facility

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**Abstract.** Since its completion in 2009, the National Ignition Facility has been operated in support of NNSA's Stockpile Stewardship mission, providing unique experimental data in the high energy density regime. We will describe the progress made by the National Ignition facility in the user office and management, facility capabilities, target diagnostics and diagnostics development. We will also discuss the results of a major effort to increase the shot rate on NIF. An extensive set of projects, developed in conjunction with the HED community and drawing on best practices at other facilities, improved shot rate by over 80% and recently enabled us to deliver 356 target experiments in FY15 in support of the users. Through an updated experimental set-up and review process, computer controlled set-up of the laser and diagnostics and disciplined operations, NIF also continued to deliver experimental reliability, precision and repeatability. New and complex platforms are introduced with a high success rate. Finally we discuss how new capabilities and further efficiency improvements will enable the successful execution of ICF and HED experimental programs required to support the quest for Ignition and the broader Science Based Stockpile Stewardship mission

## 1. Introduction

The National Ignition Facility is the world's largest laser facility for Inertial Confinement Fusion (ICF) and High Energy Density (HED) science research. NIF is a 192 beam Nd-glass laser system that has demonstrated operation producing 1.8 MJ of 0.35  $\mu\text{m}$  wavelength light with more than 500 TW of peak power.[1] Completed in 2009, initial experiments were done through 2012 as part of the National Ignition Campaign (NIC) conducting ignition and supporting experiments using indirect drive to implode cryogenic layered DT ignition CH targets.[2] NIF supports four main programs as part of its role in the NNSA's Stockpile Stewardship program: ICF, HED, Discovery Science (DS), and other National Security Applications (NSA). NIF is increasing its shot rate to provide increased opportunity for all its users. It continues to enhance its capabilities for improving efficiency and providing expanded capabilities for its users.

NIF continues making progress toward its ignition goal. Implosion experiments done using laser pulses producing high adiabat and lower instabilities growth implosions have resulted in implosions with significant heating of the DT fuel due to energy redeposition from the fusion produced alpha

particles.[3] Symmetry control and laser-plasma instabilities in these gas-filled hohlraums remain an issue.[4] The support tents that hold the capsule in place were found to provide a seed for hydrodynamic instabilities also distorting the imploding fuel.[5] Experiments are presently investigating hohlraum dynamics to improve symmetry control and laser plasma instabilities. New methods for supporting the capsule are being developed to reduce the effect on implosions. NIF is also doing experiments to broaden its ICF studies using alternative ablators such as high density carbon (HDC) [6] and Be [7] and investigating alternative implosion geometries such as double shell targets and foam lined capsules. A program investigating direct drive implosions on NIF has also begun.

NIF has significantly expanded its efforts in HED science. A major effort is studying materials at high pressures. It has performed experiments measuring the equation of state of carbon and iron to 5 terapascals relevant to planetary formation.[8] Platforms have been developed to measure x-ray diffraction from crystals dynamically compressed to high pressures. A platform is being developed to measure the strength of materials at high pressures by measuring the reduction in growth of hydrodynamic instabilities due to strength. The long pulses and high energy of NIF allows it to study hydrodynamic instabilities in unique regimes. NIF is performing experiments studying complex hydro in shear flow into nonlinearity. NIF has developed the capability to delay beams by tens to one hundred nanoseconds to produce x-ray backlighters to enable these experiments. Experiments have also begun to measure nuclear cross sections using NIF implosions. The relatively pure 14 MeV neutron source and low background offer the possibility of making high fidelity cross section measurements, NIF is also being developed as a low debris, high power x-ray source for x-ray effects testing.

## 2. Improved NIF Operations

NIF has continually worked to improve its operational efficiency. The number of NIF target shots by quarter is shown in figure 1. NIF performed 356 target experiments in FY15, far exceed the stretch goal of 300 laid out in the 120-day study. The same study had a stretch goal of 400 target shots in FY16. The four main programs utilizing the NIF have all benefited from the increase in shot rate. This is consistent with the goal of NIF to be a user facility serving a broad base of users. NIF has established a NIF user group and has an annual meeting of the users to discuss issues and plan for future development of the facility. [9]

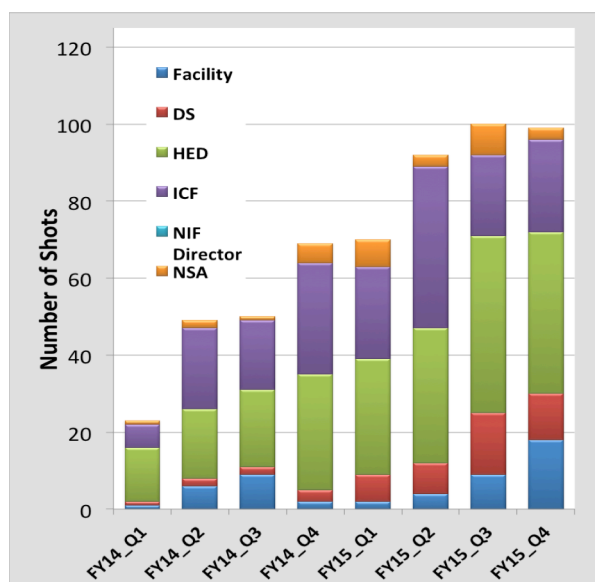


Figure 1, NIF shots by quarter. Actual shots through Q3 of FY15. Planned shots for Q4 of FY15.

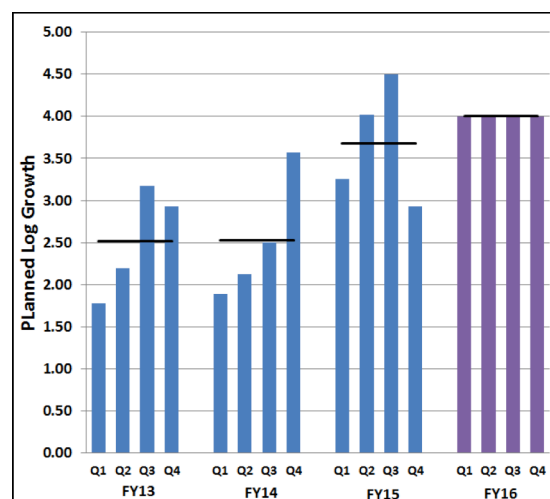


Figure 2. NIF final optics usage



A significant improvement in the shot rate has been due to operational efficiencies. A number of workshops were held in 2013 with operations managers from other large facilities and a number of potential improvements were identified. NIF has adopted a fixed schedule for target shots and maintenance. The operations crew has examined all of its procedures streamlining many of them making it more efficient. A number of hardware changes have been engineered to improve efficiency. The NIF User Office, working with NIF Data Systems has also improved its user interfaces, improving and streamlining the tools needed for experimental set up. NIF continues these efforts as part of its continuing improvement program.

To meet its user requirements, NIF routinely operates above the  $3\omega$  laser fluence damage threshold for its final optics. Part of managing operational efficiency is managing optics use. NIF optics usage is shown in figure 2 in terms of log growth of damage sites that is a measure of optics damage. Currently, the facility replaces  $\sim 40$   $3\omega$  optics per week. A recycle loop has been developed to mitigate and repair damaged optics, and lower the cost of operating above the damage threshold. NIF has an active program for improving damage thresholds. This includes improving finishing capabilities and managing optics damage. As these technologies are introduced into production operations at higher damage growth is possible, as seen in figure 2, which enables users to request higher energy for experiments without significant additional cost, improving operational efficiency.

Improvements are also being made in efficiencies for target fabrication to meet the demands of an increasing shot rate. Most of the indirect drive target components are manufactured at General Atomics while assembly and metrology are done at LLNL. In recent years target fabrication has moved to a clean room environment to improve target quality and yield. Improved efficiencies are being realized by increasing automation. Examples of these are shown in figures 3 and 4. Figure 3 shows a photograph of an automated proofing station that can process twice as many targets as the old proofing station. An automated robotic hohlraum insertion and alignment station is shown in figure 4. These streamlining projects are expected to increase target fabrication capacity by 30-50%.

Target chamber hardware is being added to improve shot capabilities and efficiency. The Advanced Target Laser Alignment System (ATLAS) is being commissioned for faster and more accurate target and diagnostic alignment. The system consists of a laser and sensors that can monitor inside the targets chamber the position of fiducials placed on diagnostics and other hardware for accurate positioning.



Figure 3. Automated proofing station



Figure 4. Automated robotic hohlraum insertion and alignment

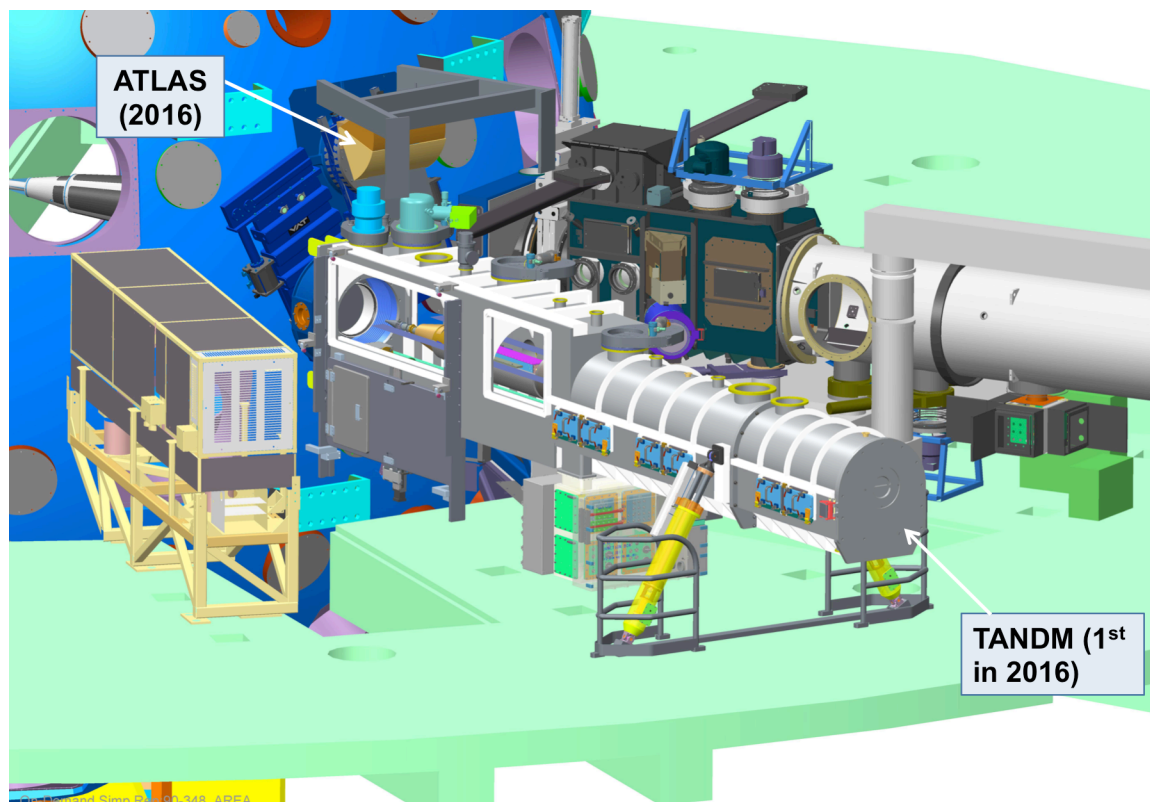


Figure 5, CAD drawing showing the position of the ATLAS and TANDM hardware

The system will replace the Opposed Port Alignment System (OPAS) presently being used for DIM instrument alignment freeing up valuable real estate at the equator of the target chamber. The system has already demonstrated that it can align diagnostics on the Polar DIM that in the past has been difficult since it did not have an OPAS. A new manipulator called the Target and Diagnostic Manipulator (TANDM) is being added. TANDM will be able to field DIM based diagnostics and serve as a warm target positioner. This addition will provide another view of the target for diagnostics and flexibility for target fielding.

### 3. New Diagnostic Capabilities

NIF continues to add to its impressive diagnostic capabilities. The Advanced Radiographic Capability (ARC) for high energy backlighting was commissioned in 2015. New x-ray imaging and x-ray spectroscopy capabilities have recently been added. New implosion diagnostics are being implemented to provide near polar views of the implosion.

ARC adds short pulse capability to the NIF beams using chirped pulse amplification. A chirped pulse is generated in the NIF ARC preamplifier and stretched for amplification. Large gratings in the target area recompress the beam that will be focused near chamber center on targets to produce high energy backlighting for radiography of high areal density targets such as ICF capsules or high-Z hydrodynamics experiments. Initially two NIF beams will be converted to short pulse with each beam segmented into two beamlets. Initial operation is planned for each beamlet to operate at 0.9 kJ in a 30 ps pulse for intensities greater than  $10^{17}$  W/cm<sup>2</sup>. Shorter pulse lengths and higher energies will be commissioned in the future.

New X-ray imaging and x-ray spectroscopy capabilities are being developed. The Dilation Imager for X rays at Ignition (DIXI) [10] is a new x-ray imager developed at General Atomics that can image the imploding core of ICF targets with 10 ps resolution, more than five times faster than previous systems. DIXI converts an x-ray image to an electron image at a photocathode. The electron image is

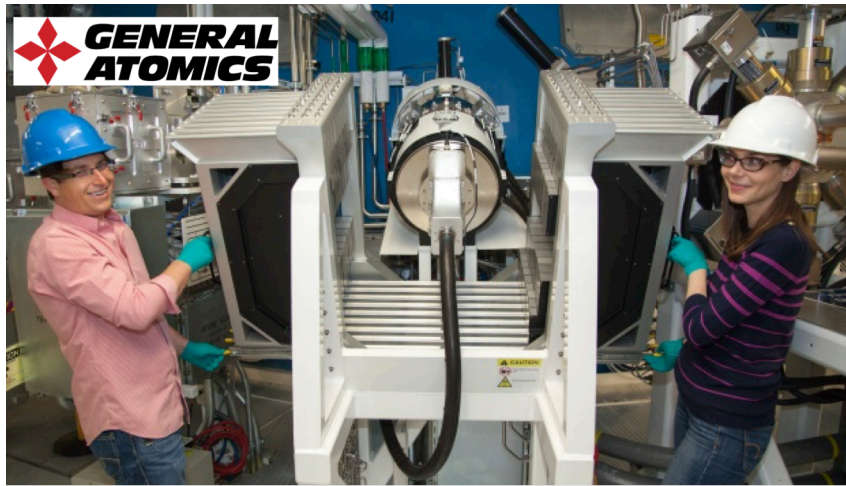


Figure 6. DIXI mounted on the NIF target chamber

accelerated using a ramped voltage to time dilate the image, transported by an imaging magnetic field to a gated detector. DIXI mounted on the NIF chamber is shown in figure 6. DIXI has already shown implosion features not observed in standard gated images due to the poorer time resolution. DIXI also has an advantage that it is well shielded since it is outside of the target

chamber allowing it to operate on yield shots. Time resolution has been added to one of the Static X-ray Imagers to time resolve the x rays produced by the lasers hitting the hohlraum wall. A two-frame Single Line of Sight (SLOS) camera developed at Sandia National Laboratories has been retrofitted to the lower SXI producing two-dimensional images with 2 ns resolution. Four frame and eight frame versions of the camera are planned for a number of other applications.

Several x-ray spectrometers are being developed for NIF experiments. The NIF X-ray Spectrometer (NXS), designed and built by LLE at the University of Rochester, mates to an x-ray streak camera for recording time resolved spectra.[11] It can be fielded with ten different elliptically bent crystal configurations to cover the spectral range from 2 keV to 18 keV. The spectrometer has been used to measure x-ray line intensities of tracers to characterize hohlraum conditions. A time integrated x-ray spectrometer, VIRGIL, is being fielded to measure the x-ray spectrum from 1.5 keV to 6 keV along the Dante line of sight. The spectrometer will be used to better characterize the x-ray spectrum in the band for better fidelity measurements of x-ray preheat. Additional spectrometers planned include a high resolution spectrometer to measure line width of Kr K-shell radiation for characterizing imploded cores and a high resolution spectrometer for opacity experiments.

Experiments and calculations indicate that ICF implosions may have significant anisotropies. Three-dimensional simulations show distorted cores due to drive asymmetries and target features. Nuclear activation detectors (NAD) placed around the chamber measure an anisotropy attributed to variations in the shell areal density.[12] Low mode asymmetry from hohlraum symmetry has been measured along two orthogonal lines of sight, but most other measurements have a limited number of views. New lines of sight for other nuclear diagnostics are being developed to obtain a more complete understanding of the implosion. Neutron time of flight (nToF) spectrometers are used to measure the DT and DD neutron yields and ion temperature and to measure the DT down scatter ratio.[13] NIF currently has three lines of sight, two nearly orthogonal near the equator and one near the bottom of the chamber or south pole. A fourth line of sight is being added to the north pole with the detector on the roof. This will have two detectors with



Figure 7. The NXS being fielded on a DIM at NIF



nearly opposing views to detect if there is bulk motion of the fuel at stagnation. Presently there is only one line of sight at the equator for the Neutron Imaging System (NIS).[14] A second line of sight near the top of the chamber is being developed. A third line of sight orthogonal to these two views is being considered. An additional line of sight for DIXI near the top of the chamber is also being planned.

#### **4. Summary**

NIF continues to develop as a unique experimental facility for HED research. It is improving both its operations efficiency through operational improvements and equipment and expanding its shot rate to accommodate the requests of its large user base. All NIF programs saw their shots and capabilities increase: ICF, HED, the Discovery Science programs and National Security Applications. NIF is adding new target experimental capabilities and platforms benefiting. The ARC laser capability was completed in 2015 providing short pulse capability on four beamlets for high energy backlighting and short pulse physics research. NIF continues to add target diagnostics capabilities incorporating state of the art techniques, consistent with the National Diagnostics Plan. The facility provides new and exciting physics data supporting scientific progress in all areas of the HED science and NNSA's Stockpile Stewardship Program.

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